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DEVELOPMENT OF AN ADVANCED OPTO-ELECTRONIC IMAGING TECHNIQUE FOR SAMPLING MID-WATER NEKTON USING OPTICAL PATTERN RECOGNITION

Unsolicited Proposal

To

OFFICE OF NAVAL RESEARCH

ARLINGTON, VIRGINIA 22217

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I. INTRODUCTION:

The study of the marine ecology requires quantitative estimates on the standing stocks of nekton to assist in evaluating the structure and dynamics of marine ecosystems. Nekton populations comprise a large portion of the living biomass and may have a major role in recycling of elements and regulating the structure of population at lower trophic levels.

As no one method of sampling is adequate for an understanding of the nekton role in the marine ecosystem, a judicious mix of techniques and technologies that complement each other could increase the ability to assess nekton populations.

For the basis of the ensuing discussion,meso-pelagic(mid-water) nekton includes animals capable of moving from place to place between 200 to 2000 meters. By definition, this consists primarily of vertebrates(fish),squid(Cephalopods) and some forms of higher crustaceans(Decapods). The great mass of invertebrates is excluded due to the lack of directed and sustained locomotion.

Quantitative analysis of nekton populations can provide valuable data pertinent to food web composition, estimation of commercial and sports fisheries harvest and investigation of bioacoustics phenomena.

Sampling *per se* in meso-pelagic waters is compounded by the lack of a single technique capable of providing reliable identification and enumeration of all species within a search area. Basically, the problem can be defined in terms of biological and non-biologacal factors limiting the suitability of equipment currently being used for this purpose:

TRAWLS

Mid-water trawls of the U.S. fleet are limited to small pelagic animals due to inadequate nets ($\sim$200 meters^2 mouth opening) and the inability to sample at discrete depths. Net avoidance is observed among strong swimmers and can only be overcome in part by using 1600 mesh nets with mouth openings of 1000 meters^2 or larger. Operation of such nets is very expensive as well as requiring specially equipped vessels for their deployment.

EGG AND LARVAL STUDIES

Low cost ichthyoplankton surveys have been popularized for investigating population dynamics of fishes, detection and appraisal of fishery resources and studies in biology and systematics. Abundance and distribution of adults can only be monitored by this method in the spawning area during the spawning season. Sampling is generally considered to be very poor in surveys of this type compared to that obtained by acoustic eggs or larvae, or being demersal in nature, would not be detected by this method. Thus, the value of mid-water ichthyoplankton surveys in estimating adult biomass is seriously limited.

ACOUSTICAL TECHNIQUES

Low frequency (broadband systems) studies of mesopelagic nekton provide excellent information on the presence or absence of fish with swim bladders. In particular this has provided detailed insight into the vertical migration(diurnal) of Mycophidae and siphonophores of the suborder Physonectae.

The former, characterized by lantern fish, have a gas-filled swim bladder resonant for sound pulses from 12 to 24 kHz. Physonectae,polymorphic coelenterates containing bubbles of carbon monoxide,similarly respond to echo sounder frequencies. Although acoustical techniques for assessment of nektonic populations provide acceptable levels and continuity of sampling, the method had has several short comings: Fish without swim bladders can not be detected and species identification and packing densities requires anciliary data as trawls for verification.

REMOTE SENSING

Direct aerial observations and photography, including multispectral imaging, are limited to nekton in epipelagic waters under the best of environmental conditions.Some fish are known to have unique spectral signatures and can be identified from the air. Tuna schools are routinely tracked at night and biomass estimates made by virtue of the intensity of the bioluminescent signal from disturbed waters. This would not be seen under conditions of ambient lighting or adverse weather conditions. Again, anciliary information is required to confirm the accuracy of the airborne data.

DIRECT OBSERVATION BY SUBMERSIBLES, TELEVISION AND PHOTOGRAPHIC METHODS

Valuable data has been obtained from submersibles in the mesopelagic zone and has provided basic information on the vertical (diurnal) migration of sound scattering layers. Unfortunately use of such craft is not practical for large area surveys due to the limited "window" (sampling area) for TV,cameras and observers. The latter may not be able to identify all nekton observed and sample collection capability is usually quite limited. It also appears that some nekton may avoid submersibles,possibly due to lights,motor sounds etc. and only be seen as a matter of chance. Based on comparison of operational costs and the amount of data retrieval, submersibles are highly impractical for meso-pelagic surveys. Populations have been surveyed by operation of conventional remote surveillance systems; however, concern exists that studies of motile animals may similarly be influenced by sounds,lights and mechanical disturbances.

FOOD HABITS

Examination of the stomach of carnivores, e. g., seals, sperm whales, dolphins and porpoises, salmon etc., can provide valuable information regarding nektonic composition throughout the water column. In many instances large and small nekton infrequently caught in nets are extensively seen in the stomachs of sperm whales and Alepisaurus sp., respectively. Based on the aforegoing it can be readily seen that non of the techniques currently in use can satisfactorily provide unbiased and statistically valid profiles of meso-pelagic nekton. Common problems shared in most cases include:

1. Inadequacy of sample.
2. Aversion phenomena associated with environmental disturbances (light, sound and /or mechanical).
3. Difficulty of correlating survey methods with species identity and density of biomass.

4. Lack of real-time capability for vertical and horizontal profiling.
5. Requirement for manual sorting of trawls and species identification by taxonomista.
6. High cost in relationship to the quality and quantity of data.

It is not expected that a new system can circumvent all of the problems, but suggest that the "window" of an advance nekton optical monitoring system would be comparable to an 1000 m^2 opening of nets currently in use on West German, Polish and Soviet research vessels.

Although net sampling is the most direct sampling technique, it appears that the avoidance of motile animals and bias produced by the net size is a serious problem. In order to augment the net sampling technique and to obviate the disadvantages of the systems indicated above, the development of an opto-electronic imaging system using an optical pattern recognition scheme to be used in conjunction with an existing towed fish is proposed that:

a. produces a mouth opening equivalent to that encompassed by large nets
b. uses monochromatic light which minimizes the effect of lights on motile animals characteristic of white light sources
c. provides the requisite recognition parameties to identify and count nekton density
d. minimizes backscattering which limits contrast in conventional TV systems

e. transmits only useful information thereby reducing information storage capacity

II. BACKGROUND WORK:

The motivation for developing a system for recognizing and sampling mid-water nekton using pattern recognition techniques stems from the "Workshop On Problems Of Assessing Population Of Nekton", held in Santa Barbara, Calif. in 1975 sponsered by ONR and the National Science Foundation.

In May of 1977, General Sensors, Inc. received a 4-month study contract from ONR to study the feasibility of developing such a system by using optical imaging in conjunction with an"intelligent" computer (i.e. a system capable of recognizing preprogrammed nekton characteristics). This system is eventually to be integrated into a towed fish system currently being developed by the Navy.

This preliminary study has indicated that the following criteria are necessary for a viable deep water imaging and counting system:

1. The system can only be used to recognize and count nekton of grossly different morphology (it has been suggested by Dr. R. Williams of NSF that it may be possible to differentiate species by their mode of swimming).

2. The myctophids and euphasiids represent the lower limit of nekton recognition based on size and reflectivity.

3. The imaging system must operate at relatively close range- on the order of 20 meters- in order to be able to recognize the variety of nekton.

4. In order to achieve the largest possible sampling volume, the illuminating beam used in the towed fish should be directed in some circular fashion.

5. Resolution and hence recognition is detector limited and not limited by the sea-water transfer function.

6. A viable system must incorporate a recognition scheme to be

able to count in real time the expected number and variety of nekton.

Currently, the work is being continued under a seperate contract with ONR in which the recognition parameters of perimeter, area and pseudo-volume in two demensions along with bioluminescent characteristics are being examined.

III. TECHNICAL APPROACH:

A. Background:

Although the orginal intent of this program was to develop a recognition system utilizing a computer recognition scheme, it has become apparent during the course of this work that such a system will not meet the design criteria of a viable recognition and counting system. This change in direction is the result of the following requisite characteristics of a recognition and counting system:

(a) due to the increased costs of available ship time, a towed fish must move more rapidly to gather more data in a shorter time than originally envisioned (i.e. from 1 knot to 10 knots).

(b) due to the enormous costs involved in testing any counting system in the ocean, it is more desirable (i.e. economically and for purposes of calibration) to be able to test a developed system on a simulator that can reasonably imitate the following variables encountered in ocean testing:

1) motion of the towed fish
2) sea transfer function with range
3) orientation of nekton
4) background scattering
5) attenuation of the sea water
6) detector characteristics
7) bioluminescent characteristics of the nekton

The inability of present day computer technology to cope with requirement (a) above can be seen from the following considerations. Assuming a modest image format of 100x100 image elements (i.e.regardles of how the image is formed), a relative motion between the towed fish and nekton of 10 knots (about 500 cm./sec.) will produce a smearing of each object point or resolution element. A modest resolution element in object space for lantern fish is about 1mm. To minimize object blur and hence image blur, we require the blur to be no more than 1/10 of the resolution element or .1 mm to maintain the image quality of the static case. Taking a worst case situation, we require that each resolution element be recorded in 2×10^{-5} sec. For a 100x100 image format, this results in an image being recorded every 2×10^{-5} sec. In a sequentially recorded system, this results in a pixel (i.e. picture element) transmission rate of 5×10^{8}/sec. If 4 bits represents each pixel (8 levels of grey), then we need a transmission rate of 2×10^{9} bits/sec. This is well beyond the state-of-the art for small systems. Although this is a worst case situation and under certain situations the rate is well below this, if the system is to be usable in the real world, we conclude that sequential processing cannot be used. Parallel processing becomes necessary in order to achieve the required image quality under high towing rates. This suggests that optical processing should be used if possible. Although optical processing is not at the stage of development that image computer processing is, it is sufficient to meet the requisite constraints for a viable counting system.

The second constraint, (b) above, suggests the use of optical processing also for the simulator. As will be shown below, proper optical design will reasonably simulate the listed variables above using incoherent light.

B. Theory:

1. Background:

It would take us too far afield to describe fully the theory of of image formation using the concept of linear spatial filter theory. Many excellent texts have been written describing the theory. The text by O'Neill[1] is the classic in the field. We only present here the salient features of the theory in order to describe both the simulator and the optical image processing proposed for this work.

In incoherent light, an image formed by any optical system can be considered to be the convolution of the system spread function s(x) (i.e. response of the optical system to a point source) with the object intensity distribution $O(\varepsilon)$. Here x and ε refer to two dimensions. Hence we can write,

$$I(x) = s(x) \odot O(\varepsilon) \tag{1}$$

where, $I(x)$ = resultant image intensity distribution

$\odot$ = mathematical convolution

Fourier transforming (1) results in,

$$I(\omega) = \tau(\omega) \cdot O(\omega) \tag{2}$$

where, $I(\omega)$ = image optical spatial frequency spectrum

$\tau(\omega)$ = optical tansfer function

$O(\omega)$ = object spectrum

ω = optical spatial frequency

It is noted that whereas there is a convolution in image space, there is simple multiplication in frequency space.

Since s(x) can be written as,

$$s(x) = A(x) \cdot A^*(x) \tag{3}$$

where, $A(x)$ = amplitude image distribution function

$A^*(x)$ = complex conjugate of $A(x)$

Then, the Fourier transform of s(x) becomes,

$$\tau(\omega) = P(\omega) \odot P^*(\omega) \tag{4}$$

where, $P(\omega)$ = exit pupil function expressed in spatial frequency units

$P^*(\omega)$ = complex conjugate of $P(\omega)$

Consequently, the effect on imaging by an optical system can be modified according to the form of the exit pupil of the system. The resultant modification on $\tau(\omega)$ produces the kind of image quality formed in frequency space. The mathematical operation of convolution (autocorrelation for a symmetric function) for a symmetric pupil function is simply the translation of the pupil function over itself. In many cases, this can be done graphically. For example, for a rectangular pupil function, the resultant $\tau(\omega)$ is a linear decreasing function. For other pupil functions, more complicated $\tau(\omega)$'s result.

2. Optical Simulation Of Sea Parameters:

From an economical point of view and in terms of calibrating and determining the effectiveness of a developed recognition and counting system, it is desirable to be able to simulate those parameters that will be encountered in sea testing. Although, all the parameters cannot be simulated exactly, enough of the important parameters can be simulated so that the performance of a developed system can be experimentally verified without sea testing.

(a) Simulation of Uniform Motion in One Direction:

It can be shown[2] that linear motion of the image in one direction will affect the transfer function according to,

$$\tau(\omega_x) = \tau_0(\omega) \sin(\omega_x L/2)/\omega_x L/2 \tag{5}$$

where, $\tau_0(\omega)$ = transfer function for static image

L = v times t

v = velocity of moving image

t = integration time

From equation (4), the transfer function can be represented by the autocorrelation function of the pupil function. Consequently we need a representation for,

$$P(\beta)\,P^*(\beta-\omega_x) \tag{6}$$

For pure phase variations, that is for $P(\beta) = e^{-ik\Delta(\beta)}$, a phase error of the form $\Delta(\beta) = a_n \beta^n$ produces an integrand in equation (4) of the form,

$$P(\beta)\,P^*(\beta-\omega_x) = e^{+ikw(\beta,\omega_x)} \tag{7}$$

where, $w = \Delta(\beta) - \Delta(\beta-\omega_x)$ is a polynomial of degree n-1 in β. For n = 2, the resultant polynomial represents a focussing error of the form $\Delta(\beta) = b_1(\beta/\beta_0)^2$ where,

$$\beta_0 = \frac{2\pi a}{\lambda F} \tag{8}$$

with a the radius of the pupil, F, the focal length of the lens and b_1, the magnitude of the focussing error given by,

$$b_1 = \frac{a^2 \Delta l}{2F^2} \tag{9}$$

with Δl = the distance the lens is out of focus. It can be shown(2) that when b_1 is greater than 2λ, the resultant transfer function is,

$$\tau(\omega_x) = \frac{\sin(\omega_x d)}{\omega_x d} \tag{10}$$

where 2d is the diameter of the defocussed spot (geometrical approximation).

For b_1 greater than 2λ we have that,

$$\frac{a^2 \Delta l}{2F^2} \geq 2\lambda \tag{11}$$

or,

$$\Delta l \geq 16 \lambda F_{\#}^2 \tag{12}$$

where $F_{\#}$ = f number of the lens. From equation (5), we find the equivalence as,

$$L = 2d \tag{13}$$

or L represents the diameter of the defocussed spot size. Consequently, defocussing in one demension is optically equivalent to linear image motion and the magnitude of L can be simulated by the amount of defocussing through equation (12). Finally image motion can be related to object motion by knowing the object range.

(b) Sea Transfer Function With Range:

It has been shown by Wells[3], that the transfer function for sea image transmission can be written as,

$$\tau(R,\psi) = e^{-D(\psi)R} \tag{14}$$

where $D(\psi)$ = decay function/distance

R = range

ψ = spatial frequency in terms of radians (frequency) per radians (angle).

It has been shown by Wells that for the focussed case,

$$D(\psi) = \alpha - \frac{s\left[1 - e^{-\psi\theta_0}\right]}{\psi\theta_0} \tag{15}$$

where α = attenuation coefficient

s = scattering coefficient

θ_0 = characteristic angle of the volume scattering function

Consequently, the sea scattering parameters and attenuation can be used to determine the $\tau(R,\psi)$ directly. Calling $[1-e^{-\psi\theta_0}]/\psi\theta_0$, Y, equation (15) becomes $D(\psi) = \alpha - sY$ or,

$$\tau(R,\psi) = e^{-\alpha R} \cdot e^{sYR} \tag{16}$$

where $0 \leq Y \leq 1$. When $Y = 0$, $\tau(R,\psi) = e^{-\alpha R}$ and there is no scattering. When $Y = 1$, $\tau(R,\psi) = e^{-(\alpha - s)R}$ or $e^{-\gamma R}$ where γ is the broad bean attenuation coefficient. Consequently, $\tau(R,\psi)$ at $\psi = 0$ is $e^{-\gamma R}$ and decays exponentially to $e^{-\alpha R}$ as $\psi \to \infty$.

In order to simulate this function in τ, we need an attenuation given by $e^{-\gamma R}$ with an exponentially decaying function according to equation (16). An excellent approximation to this function can be obtained optically by considering the spherical aberration of a lens. From equation (7) and what follows there, when $n = 4$ we have that,

$$\Delta = C_1 \left(\beta/\beta_0\right)^4 \tag{17}$$

which represents spherical aberration at the paraxial focus. The magnitude of C_1 is given by,

$$C_1 = \frac{\Delta L}{F_{\#}^2} \tag{18}$$

where ΔL = distance between the paraxial focus and marginal focus. By irising the lens, the value of ΔL can be varied to simulate different amounts of spherical aberration and hence varying degrees of exponential decay. By suitably choosing the $F_{\#}$ and the shape factor of the lens, a wide range of the sea transfer functions can be simulated in a continous fashion.

(c) Orientation, Background Scattering And Attenuation:

Orientation is simply accomplished by object rotation, while background scattering is introduced seperately as background light and attenuation is simulated by crossed polarizers in the system.

(d) Detector Characteristies:

In the above analysis it was tacitly assumed that the image resolution was controlled by the transfer function. Under conditions of weak illumination, the system becomes noise limited rather than transfer limited. The relating equations in terms of threshold contrast requirements have been developed by Hodara[4] and are based on the premise that the threshold detector contrast is given by,

$$C_D = SNR/\sqrt{N_t} \tag{19}$$

where C_D = threshold detector contrast

N_t = total number of photons per unit area

He has shown that equation (19) can be cast into terms of the detector characteristics as,

$$SNR \cdot \nu = C_D \sqrt{\frac{Q\ N_t}{1 + N_n/N_t}} \cdot \tau(\nu) \tag{20}$$

where, ν = spatial frequency (cycles/mm)

Q = quantum efficiency of the detector

N_t = total number of photons /mm^2

N_n = noise photons /mm^2

$\tau(\nu)$ = transfer function

For weak illumination and low resolution $\tau(\nu)=1$ and equation (20) becomes,

$$SNR \cdot \nu = C_D \sqrt{\frac{Q\, N_t}{1 + N_n/N_t}} \tag{21}$$

For strong illumination and high resolution, equation (20) becomes,

$$\nu = \sqrt{Q N_t [C_D/SNR]^2}\ \tau(\nu) \tag{22}$$

or transfer limited. For each detector type, specified by Q and N_n, a plot of $SNR \cdot \nu / C_D$ versus N_t for weak illumination determines the detector requirements. For the strong illumination case, a plot of ν versus N_t $(C_D/SNR)^2$ determines the detector's "seeing" ability. In either case, the dominance of either N_n or $\tau(\nu)$ will be determined by detector type and N_t. To simulate the different conditions, it is only necessary to monitor N_t in the image and the detector seeing ability can be determined from equation (20) with input parameters of SNR, C_D, Q and N_n. It is proposed to simulate this parameter by simply measuring the photon flux in the image plane and relating this to the detector characterics through equation (20).

e) Bioluminescence Simulation:

We have shown in our previous work (Progress Report #1, Contract No. N00014-78-C-0253) that the spatial arrangement of the photophores in principle might be used for identification of the myctophid species.

Due to the expected high data rate necessary, it appears that this would be extremely difficult. However in order to experimentally verify this, it is proposed to simulate the biolumescent photophores as follows.

In the input object plane, a mask is prepared simulating the photophoric arrangement. This is diffusely illuminated in monochromatic light of controlled intensity ($\lambda \sim 480$ nm) and passed through the simulator. The various parameters are applied and the resultant image is examined either visually or eventually with the pattern recognition system. The results of this type of testing will determine whether this parameter is a viable means of identifiction.

f) Summary :

The proposed optical simulator to produce the various effects discussed above is shown in figure 1. The input object to be used can be film or direct projection from a specimen of lantern fish. To this end,it is proposed to examine the lantern fish specimen collection at the Smithsonian Institute to determine the best approach to use for the object input.

3. Optical Pattern Recognition:

As mentioned above, due to the rapid towing rates desired for the recognition and counting system, it appeared that computer sequential image processing is not adequate and a parallel processing system is necessary.

It is the purpose of this phase of the work to examine the practicality of using Fourier transform principles to do the recognition and counting utilizing a hybrid optical/computer system. It is intended to work entirely in frequency space as motion of the object does not affect the transform. The transform is affected by orientation, size shape and number.

The principle to be used in developing a system is the following. In any imaging system, (disregarding the degradation due to the optics for the moment) using incoherent light, the object spectrum is the autocorrelation of the amplitude transform, i.e.,

$$\underset{\text{(Object)}}{A(\varepsilon)} \xrightarrow[\text{Transform}]{\text{Fourier}} G(\omega) \tag{23}$$

and,

$$O(\omega) = G(\omega) \odot G^{*}(\omega) \tag{24}$$

Due to the two demensional nature of the object spectrum, any asymmetry in the object will produce an asymmetrical spectrum. As the object rotates, the spectrum also rotates (orientation effect). In addition, the size of the object will determine the magnitude of the high frequency components while the shape determines the asymmetry in the spectrum. Also if two similar objects are in the field of view of the optical system in the same orientation, the resultant spectrum is the same but with twice the intensity. If three, then three times the intensity and so on.

In principle, if the resultant spectrum can be harmonically analyzed radially, the average size and shape can be determined and from the strength, the number of objects. In dealing with schools of lantern fish,(i.e. numbering in the thousands) it is not expected to be able to count the number exactly but to acheive average number, average size etc. as the fabrication of a system to count individually would be an enormous task.

In an incoherent system, it is not possible to work directly in frequency space (i.e. a physical plane) but by the judicious use of masks and lens aberrations, the object spectrum can be analyzed due to the relationship,

$$I(\omega) = \tau(\omega)\, O(\omega) \tag{25}$$

where the $\tau(\omega)$ of the optical system can be varied to analyze the $O(\omega)$. For example, if two slits are place in the exit pupil of the system, the $\tau(\omega)$ consists of a d-c term plus spectral components at $\omega_0 = \pm 2\beta_0$. By varying the distance of the slits, we are in effect harmonically analyzing the structure of the object intensity distribution. An annulus in the exit pupil effectively does the same thing except radially.

It will be the purpose of this part of the work to develop ways of:

1) radially varying the $\tau(\omega)$
2) asymmetrically varying the $\tau(\omega)$
3) determining the effects on the object spectrum

In order to keep pace with the rapidly varying object distribution, the variations in $\tau(\omega)$ must be made rapidly- possibly mechanically or even electro-optically.

To expand on the principle to be used in optical pattern recognition and counting, we utilize the geometry depicted in figure 2. Here, $O(\varepsilon)$ represents the object (objects) intensity distribution, $P(\omega)$ represents the pupil amplitude distribution at the exit pupil of the optical system (expressed as frequency units),and $I(x)$ the image plane intensity distribution where the measurements are made. Depending on the number of objects in the field of view at a given time, we denote the $O(\varepsilon)$ as,

$$O(\varepsilon) = \alpha_1 f_1(\varepsilon) + \alpha_2 f_2(\varepsilon - b_1) + \alpha_3 f_3(\varepsilon - b_2) + \cdots \tag{26}$$

where the α's reflect the maximum radiance from the objects (i.e. product of illuminating source density and diffuse reflectivity of the objects), the f's represent the radiance distribution of each object and the b's represent the location of each object referred to the center of the optical system. Equation (26) is Fourier transformed in intensity and utilizing the linearity and shift theorems, and can be written as,

$$O(\omega) = \alpha_1 g_1(\omega) + \alpha_2 g_2(\omega) e^{i\omega b_1} + \alpha_3 g_3(\omega) e^{i\omega b_2} + \cdots \tag{27}$$

In the case of a school of fish of the same family (i.e. approximately the same size with equal relectivities and oriented in the same direction), we can write,

$$O(\omega) = N \alpha g(\omega) \left[1 + e^{i\omega b_1} + e^{i\omega b_2} + \cdots\right] \tag{28}$$

where N = the number of objects.

If the distribution of the fish is random but the same orientation, then the linear phase shift terms do not acquire a finite mean value and except for local fluctuations equation (28) becomes,

$$O(\omega) = N \alpha g(\omega) \left[1 + \text{residual}\right] \tag{29}$$

From equation (4) we stated that the incoherent transfer function of the optical system can be expressed as,

$$\tau(\omega) = P(\omega) \odot P^*(\omega) \tag{30}$$

where $P(\omega)$ is the pupil function. Combining this with equation (29), we have that,

$$I(\omega) = O(\omega) \cdot \tau(\omega)$$
$$I(\omega) = N\alpha\, g(\omega) \cdot P(\omega) \odot P^{*}(\omega) \tag{31}$$

Transforming (31) results in,

$$I(x) = N\alpha\, f(\varepsilon) \odot \widetilde{P(\omega)} \cdot \widetilde{P^{*}(\omega)} \tag{32}$$

where $\widetilde{P(\omega)}$ is the transform of the pupil function. Hence,

$$I(x) = N\alpha f(\varepsilon) \odot |\widetilde{P(\omega)}|^{2} \tag{33}$$

Effectively, equation (33) indicates that the resultant image distribution can be encoded according to the pupil function transform $\widetilde{P(\omega)}$. As the form of $P(\omega)$ is at the discretion of the system designer, it can be seen that if $P(\omega)$ is a time varying function properly chosen, the resultant intensity distribution variation can be used to determine N if α and $f(\varepsilon)$ are known (i.e. shape size and reflectivity). In addition, due to the asymmetry of the nekton, the time variation of $P(\omega)$ must be done in such a way that the asymmetry can be measured. This will be the main thrust of this phase of the work.

As an example of how $P(\omega)$ affects the image coding, a simple form for $P(\omega)$ is an annulus described mathematically as a radial delta function,

$$P(\omega) = \delta(\omega - \omega_{o}) \tag{34}$$

where ω_{o} is the location of the annulus. It can be shown that the Fourier-Bessel transform of (34) is,

$$\widetilde{P(\omega)} = \omega_{o} J_{o}(\omega_{o} x) \tag{35}$$

Consequently,

$$|P(\omega)|^2 = \omega_o^2 |J_o(\omega_o x)|^2 \tag{36}$$

Substituting into equation (33) we have that,

$$I(x) = N\alpha\omega_o^2 \int f(\varepsilon)\,|J_o[\omega_o(x-\varepsilon)]|^2 d\varepsilon \tag{37}$$

Now, if the entire image is integrated then,

$$\int I(x)\,dx = N\alpha\omega_o^2 \iint f(\varepsilon)\,|J_o[\omega_o(x-\varepsilon)]|^2 d\varepsilon\, dx \tag{38}$$

or,

$$N = \frac{\int I(x)\,dx}{\omega_o^2 \alpha \underbrace{\iint f(\varepsilon)\,|J_o[\omega_o(x-\varepsilon)]|^2 d\varepsilon\, dx}_{\text{ENCODED IMAGE}}} \tag{39}$$

Since ω_o, α and $f(\varepsilon)$ are known, measurement of the total integrated image produced by the restricted pupil function is directly related to number.

It is to be noted that equation (39) is independent of the fish motion as long as the fish are in the field of view. This technique relaxes immeasurably the previous requirement of limiting the image analysis to 1/10 of a resolution element. Consequently, instead of requiring 50,000 frames/sec., we require that the harmonic analysis be made during the transit time in the field of view. For example, at a relative speed of 10 knots (5 meters/sec.) with a minification ratio of 100:1 and an image format of 5cm.x5cm., the pupil function is to varied once a second. This allows the use of mechanical variation instead of electro-optical which reflects the simplification obtained by parallel processing.

In the above analysis, it was assumed that the school of fish were oriented the same way. Under real conditions, this may not be the case and only average size and number will be obtained depending on the weighting factors of the radiance of each object. Additionally, it is to be recognized that equation (38) admits to unique solutions in N and $f(\mathcal{E})$ when ω_o is varied in a prescribed manner. In other words for a fixed N and α, only one combination of $\int I(x)dx$ with ω_o is consistent with a given $f(\mathcal{E})$.

REFERENCES

(1) Edward L. O'Neill, "Introduction to Statistical Optics", Addison-Wesley Publishing Co., Inc., London, 1963.

(2) Ibid., pg. 27.

(3) Willard H. Wells, Agard Lecture Series No. 61 on "Optics of the Sea', Agard-LS-61, Technical Editing and Reproduction Ltd., London, 1973, section 3.3-1.

(4) Henri Hodara, Ibid., section 5.2-1.

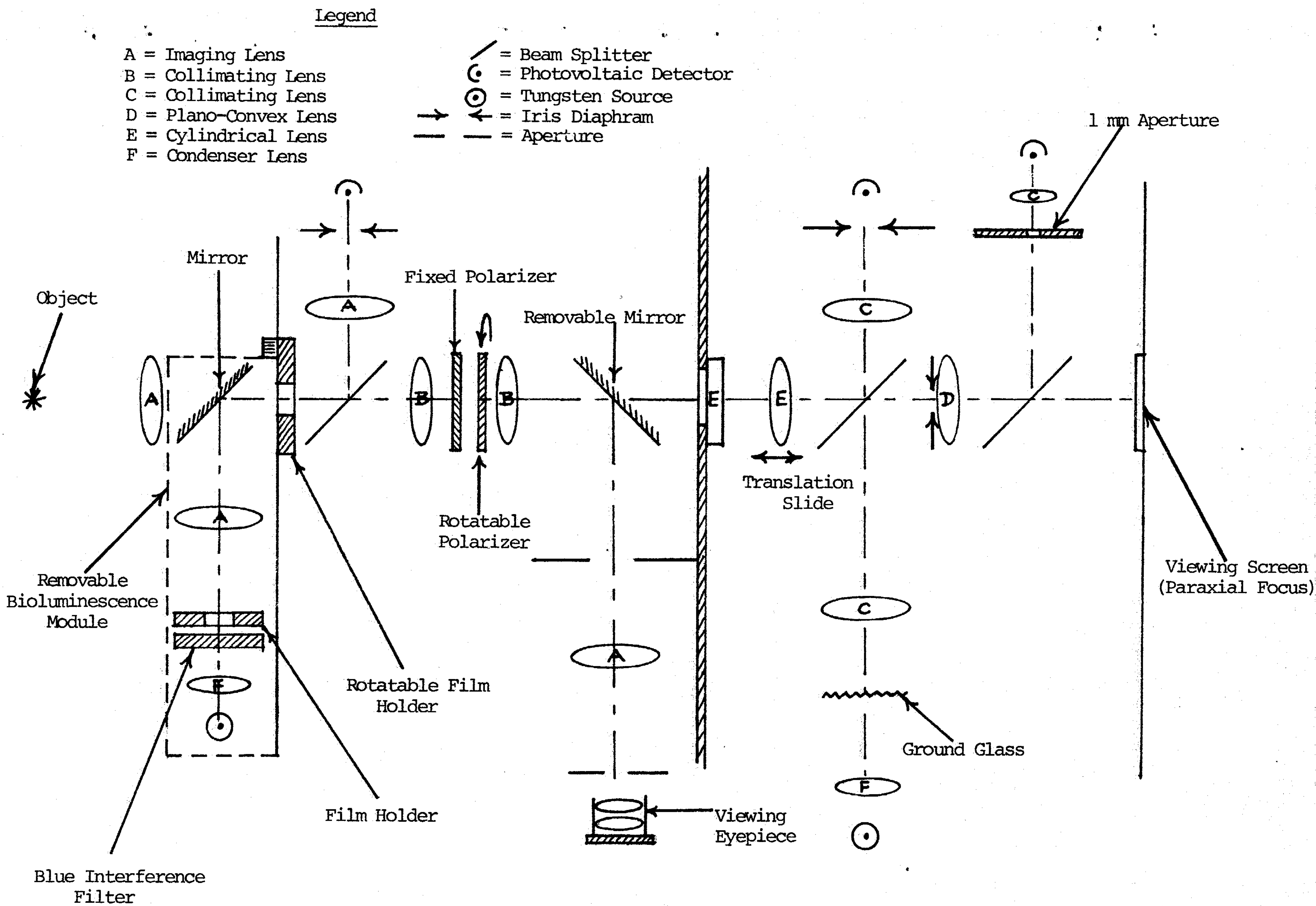


Figure 1. Optical Diagram Of Proposed Optical Simulator Of Image Degradation In Water Viewing Systems (not to scale).

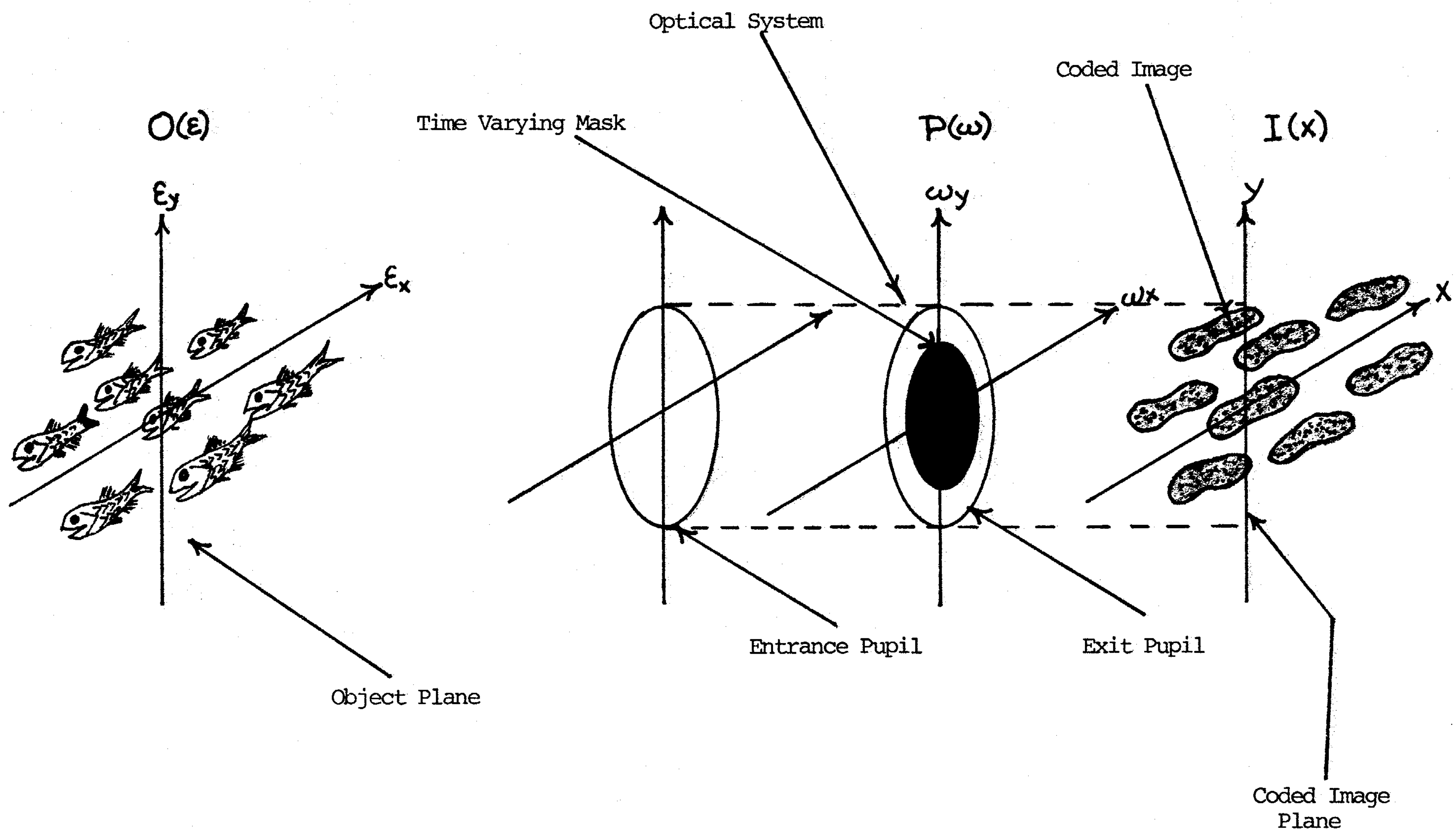


Figure 2. Geometry of Pattern Recognition System Equations Used in Text.

IV. PROPOSED STUDY AND SCHEDULE:

It is proposed to design and fabricate the optical simulator of sea parameters as described in section III B.2. In addition, it is the purpose of this work to design the optical recognition module according to the principles outlined in section III B.3. Specifically, the following tasks shall be performed:

A. Design and fabricate an optical simulator of sea parameters. As a minimum, the simulator is to simulate the following parameters:

   1) Uniform motion in one direction

   2) Sea transfer function with range

   3) Orientation, background scattering and attenuation

   4) Detector characteristics

   5) Bioluminescence of myctophids

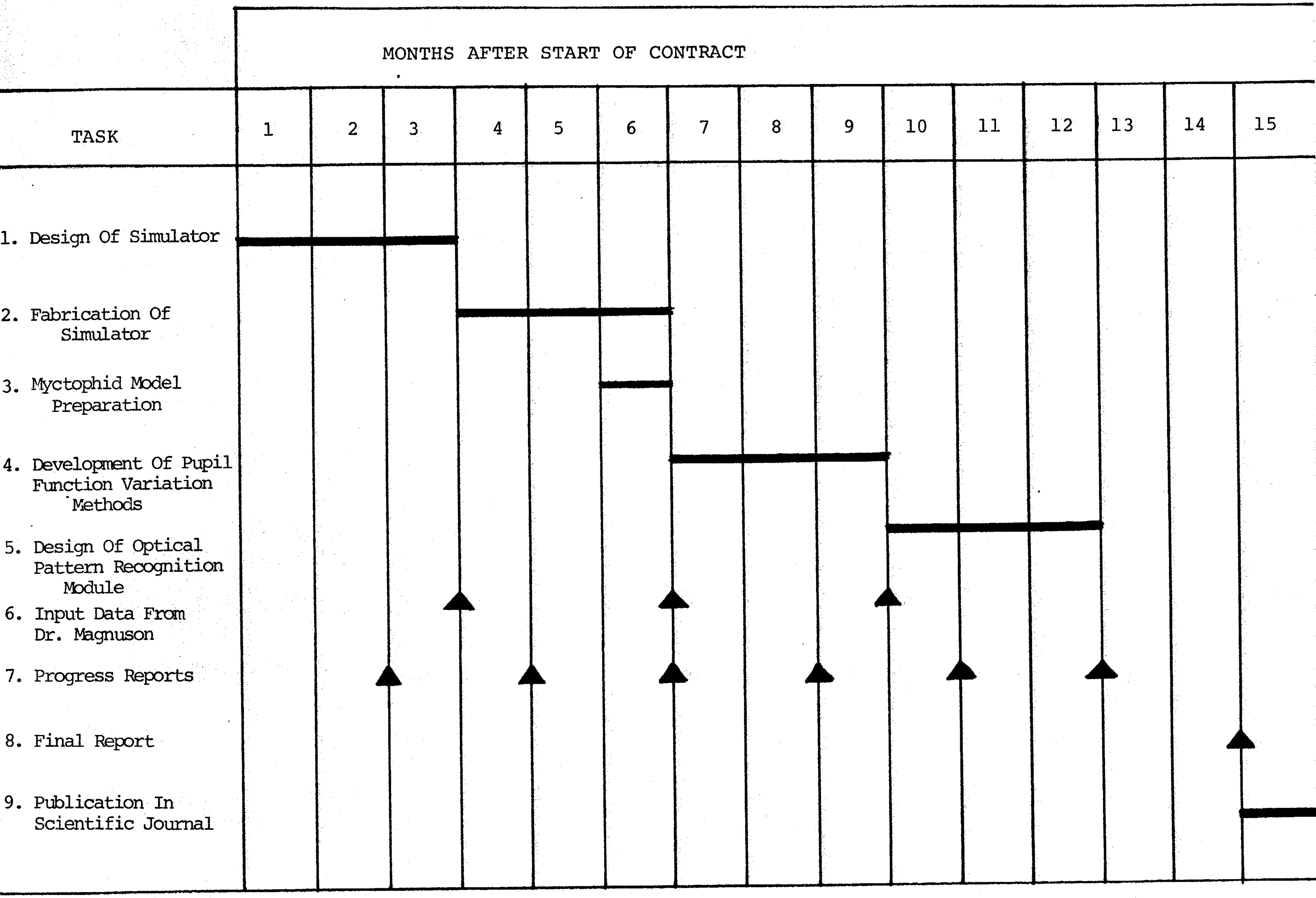
B. Utilizing the specimen collection of myctophids at the Smithsonian Institute in Washington, prepare suitable models of representative species as input objects to the simulator.

C. Design the optical pattern recognition module for myctophids with emphasis on developing methods for rapidly modifying the optical transfer function in a prescribed manner

D. Design of the optical pattern recognition module is to incorporate information concering myctophids to be supplied on an as needed basis by Professor Magnuson of the University of Wisconsin.

E. Recommendations are to be made at the conclusion of the study as to the type of viewing system to be used to make effective use of the optical recognition module developed.

MILESTONE CHART



V. CORPORATE INFORMATION & PERSONNEL:

General Sensors, Inc. was incorporated under the laws of the State of Penna. on April 11, 1973. General Sensors is presently under contract with ONR Arlington, Va. (Contract No. N00014-78-C-0253). Mr. Harry Sadjian, the president, will be the principal investigator on this program; however, for the proper implementation of this program, General Sensors will utilize outside consultants well versed in their respective fields:

1. Dr. Eric Softley- Ocean Applications Systems, Inc. at Key Biscayne, Florida- computer design requirements.
2. Professor John Magnuson, Director of Limnology at the University of Wisconsin- myctophid characteristics.

RESUME' - PRINCIPLE INVESTIGATOR

Harry Sadjian: Senior Scientist (Optics and Spectroscopy)

Education: B.A. - Temple University, 1951
M.A. - University of Penna., 1955
Studied statistical optics under Professor Edward O'Neill, Boston University, 1965.

Experience: Presently, president of General Sensors, Inc. located at Fort Washington, Pa. Currently under contract with ONR, Arlington, Va. (Contract No. N00014-78-C-0253) to study the feasibility of using optical characteristics and bioluminescence of myctophids as a means of developing a pattern recognition scheme for counting mid-water nekton. Previously, under contract with ONR, Bay St. Louis, Miss.(Contract No. N 00014-77-C-0344) determined imaging requirements for pattern recognition of mid-water nekton. During 1976-1977, conducted studies for the Naval Air Development Center in Warminster, Pa. (Contract No. N62269-77-C-0058) on passive methods of measuring atmospheric water-vapor and temperature distributions. Until December of 1975, was senior scientist at General Electric's Re- Entry and Environmental Systems Department located at Valley Forge, Pa. Consultant in the fields of optics and spectroscopy, instrumental in the design, fabrication and testing of the G.E. oil monitor development work funded by the U.S. Coast Guard involving the use of forward scattering. Worked in such diverse areas as: plasma physics; bacterial light scattering; chemical, dye and pulsed lasers; clear air turbulence; cloud visibility in the infrared, visible and microwave; holographic microscopy; Fourier optical analysis and synthesis as applied to pattern recognition; optical computer storage design and particulate scattering. Instrumental in conceiving, designing and fabricating instrumentation in chlorophyll fluorescence and pollution monitoring areas. Prior to work in environmental areas, developed instrumentation in the field of shock tube spectroscopy. Before 1956, was Section Head at Frankford Arsenal's Spectrographic Laboratory located in Phila., Pa. for a period of five years.

Selected Publications

"Study of the Feasibilty of Using An Advanced Opto-Electronic Imaging Technique for Sampling Mid-Water Nekton" Phase II, Office of Naval Research, Arlington, Va. Contract No. N00014-78-C-0253, Progress Report # 1, June 1978.

"Study of the Feasibilty of Using An Advanced Opto-Electronic Imaging Technique for Sampling Mid-Water Nekton," Phase 1, Office of Naval Research, Bay St. Louis, Miss., Contract No. N00014-77-C-0344, Progress Reports 1,2,3 and 4. Final report to be incorporated with Phase II.

"Analytical Study of Passive Techniques for Measuring Atmospheric Parameters," Naval Air Development Center, Warminster, Pa., Contract No. N62269-77-C-0058, Final Report, October 6, 1977. AD AO 45717.

"Phytoplankton Study II", classified final report submitted by the General Electric Co. to the Applied Physics Laboratory, John Hopkins University, Silver Spring, Maryland, 1975.

"Phytoplankton Study I", classified final report submitted by the General Electric Co. to the Applied Physics Laboratory, John Hopkins University, Silver Spring, Maryland, 1974.

"Shipboard Oil-In-Water Content Monitor Based on Small Angle Scattering" Dept. of Transportation, U.S. Coast Guard, Report No. 4305.5/3, Aug. 1974.

"Investigation of Methods of Extracting A Laser Beam From A Gas Dynamic Laser", Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, Tech. Report No. AFWL-TR-72-92, May 1973.

"Development of a Laser Plasma Probe", Arnold Engineering Development Center Tenn., AEDC Report No. TR-67-234, 1967.

In addition, Mr. Sadjian has written several internal reports while at the General Electric Co. The most recent are:

"Analysis of a High Capacity Optical Memory for Buoy Data Acquisition", G.E. Internal Report No. 9450-045, December 1975.

"Comparison of Detectability of Cirrus Clouds by Lidar, Infared and Visual Observation", G.E. Internal Report No.9450-005, November 1974.

VI. COST AND PRICING DATA:

1. General

The cost plus fixed fee for this program is $77,093. The hourly rate for a senior scientist has been increased from $14/hr to $16/hr. This increase reflects the increase in the cost of living since Nov. 1976 when the hourly rate was first established with the Government-approximately 14%.

The overhead rate has also increased from 76% to 83.6% while the G&A remains about the same at 8.0%. The increased rate in the overhead reflects the anticipated increasing costs for the coming fiscal year over that first established with the Government in Nov. 1976. Our new rates for the coming fiscal year were computed as follows:

A. Facilities Overhead Costs (Annualized):

	(Dollars)
1. Rent	5,400*
2. Copier Rental	904
3. Typewritter Rental	636
4. Copier Supplies	160
5. Copier Maintenance	191
6. Liability Insurance	131
7. Office Supplies	300*
8. Phone	720*
9. Car Rental & Insurance	3,000
Total A	$11,442

B. Employee Costs (Annualized):

1. Part-time Secretary ($4/hr. @ 40hrs./mo.)	1,920
2. Vacation, Sickness & Holidays	
a. Vacation (3 wks./yr., 120 hrs. x $16/hr.)	1,920
b. Holidays (9 days/yr., 72 hrs. x $16/hr.)	1,152
c. Sickness (10 days/yr., 80 hrs. x $16/hr.)	1,280
3. Insurance	
a. Workmen's Compensation	120*
b. Health	1,116
c. Life & Disability	2,080
4. Social Security & Umemployment Taxes	1,760
Total B	11,348

C. Total Overhead Costs (Annualized):

1. Facility	11,442
2. Employee	11,348
Total Overhead Costs	$22,790

D. Calculation of Applied Costs:

1. Total applied hours equals 2080
2. Unapplied Hours

a. Vacation, Holiday & Sickness	272	
b. Administration (5% x 2080)	104	
Total Unapplied Hours	376	

3. Total applied hours equals
   2080 - 376 = 1704
4. Applied cost equals
   1704 hrs. x $16/hr. $27,264

E. Calculation Of Overhead Rate:

$$\text{Overhead Rate} = \frac{\text{Overhead Costs (C)}}{\text{Applied Costs (D)}} = \frac{22{,}790}{27{,}264} = 83.6\%$$

F. Calculation Of G&A Rate:

1. Legal Costs	400*
2. Accounting ($160/mo. x12 mos.)	1,920
3. Administration (5% x 2080 hrs. x $16/hr.)	1,664
Total G&A Costs	3,984
Applied Costs (D)	27,264
Overhead Costs (C)	22,790
Total Costs	50,054

4. G&A Rate equals

$$\frac{\text{G\&A Costs (F)}}{\text{Applied + Overhead (C+D)}} = \frac{3984}{50{,}054} = 8.0\%$$

* estimated costs for fiscal 1979.

2. Royalties:

There are no royalty charges anticipated on this program.

SCHEDULE A

COST ELEMENTS

Item			Dollars
1. Direct Material:			
	a. Purchased Parts (see schedule B)	6400	
	b. Printing of Final Report	500	
2.	Total Material		6,900
3. Direct Labor:			
	Senior Scientist @ $16/hr. for 1700 hrs.	27,200	
4.	Total Direct Labor		27,200
5. Direct Overhead:			
	83.6 % of item 4	22,739	
6.	Total Direct Overhead		22,739
7. Travel (see schedule C):			
	a. Transportation	1,200	
	b. Subsistence	355	
8.	Total Travel		1,555
9. Consultants:			
	a. Professor John Magnuson- Unversity of Wisconsin (Myctophid Data)	5,000	
	b. Dr. Eric Softley-Ocean Electronic Applications Inc. - Key Biscayne Fl. (Electronic design)	1,500	
10.	Total Consultants		6,500
11.	Total Direct Costs & Overhead		64,894
12. General & Administrative Costs:			
	8.0% of item 11	5,191	5,191
13.	Total Estimated Cost		70,085
14. Fixed Fee:			
	10% Of item 13	7,008	7,008
15.	Total Estimated Cost & Fee		77,093

SCHEDULE B

PURCHASED PARTS

As the simulator is an item to be developed under this contract, the following listing of component parts to be purchased are only representative and changes may be necessary to implement the fabrication of the simulator.

A.Optical Components:

Item No.	Item	Price Ea*	Total Cost*	Vendor	Cat. No
1.	(4) Imaging lens- Triplet Achromats 23 mm dia. Designation A	52	156	M-G	01LAT007
2.	(1) Blue interference filter- 480 nm peak, 1" dia.	72	72	M-G	03FIR047
3.	(2) Collimating lens- optimized doublet achromat, 40 mm dia. Designation B.	47	94	M-G	01LAO137
4.	(3)Collimating lens- optimized doublet achromats- 18mm dia. Designation C.	27	81	M-G	01LAO058
5.	(1) Plano-Convex lens- 50mm dia. Designation D.	88	88	M-G	01LQF066
6.	(2) Cylindrical lens (mounted) 58x48mm. Designation E	75	150	K-S	031833
7.	(2) Tungsten Filament Sources- in housing with aspheric lens. Designation F	350	700	Oriel	6321/632
8.	(2) Sheet Polarizers- 2" Dia.	40	80	M-G	03FPG007
9.	(1) 1" diameter ground glass	5	5	K-S	390006
10.	(4) Plate beam splitter-2" dia.	70	280	K-S	344152
11.	(1) Wide angle Ramsden eyepiece- 10X with cross-hair	45	45	M-G	04EWR001
12.	(1) Mirror, 2" dia. 1/10 wave	63	63	M-G	02MPG011
13.	(3) Iris diaphram, 2" dia.	27	81	M-G	04IDC025
14.	(1) Precision 1mm aperture	17	17	M-G	04PIP025
15.	(1) Optical test target on glass	75	75	M-G	04TRP003
16.	(1) Marata dispersion screen 4" dia.	10	10	K-S	390024

Total Optical Components: $1,997

B. Mechanical Components:

Item No.	Item	Price Ea.*	Total Cost*	Vendor	Cat N
1.	(1) Low profile optical bed- 3 ft.	143	143	NRC	URL-3
2.	(6) Low profile optical bed-1½ ft.	75	450	NRC	URL-1
3.	(5) 2" Mirror holder	163	815	NRC	600A-2
4.	(4) 1" dia. lens holder/mount	25	100	NRC	LM-1/ LH1-1
5.	(12) base plates for items 4 & 9	10	120	NRC	BP-2
6.	(1) Film holder- X,Y travel	260	260	EL	22-838
7.	(1) Rotaable Film Holder	100	100	NRC	RSA-2
8.	(2) Cylindrical lens holder	85	170	K-S	036055
9.	(8) 2" diameter lens holder/mount	32	256	NRC	LM-2/ LH2-2
10.	(1) Translation stage	90	90	NRC	450

Total $2,504

In addition, there are miscellaneous posts, risers and shields and holders too numerous to list but is estimated at an additional $500.

Total Cost Mechanical Parts $3,004

C Electronic Components:

1.	(3) Photovoltaic detectors with operational amplifiers	115	345	EG&G	PV-444A
2.	(3) Microammeters	9	27	H&R	TM21K51
3.	(2) Variable transformer	18	36	H&R	Q5375

Total Electronic Components $408

D. Miscellaneous:

In addition to the above, there is the cost of the fabrication of the housing plus cables, screws etc. too numerous to list and is estimated at $1,000.

* Catalog prices plus 10% for inflation.

Vendor Symbols

M-G	Melles Griot 1770 Kettering Street Irvine, Calif. 92714
Oriel	Oriel Corp. of America 15 Market Street Stamford Conn. 06902
K-S	Klinger Scientific Corp. 83-45 Parsons Blvd. Jamaica, New York 11432
NRC	Newport Research Corp. 18235 Mt. Baldy Circle Fountain Valley, Calif. 92708
EL	The Ealing Corp. 2225 Massachusetts Ave. Cambridge, Mass. 02140
EG&G	EG&G Inc. 35 Congress Street Salem, Mass. 01970
H&R	Herbach & Rademan, Inc. 401 East Erie Ave. Phila., Pa. 19134

Summary Of Costs

A. Optical Components	1,997
B. Mechanical Components	3,004
C. Electronic Components	408
D. Miscellaneous	1,000
Total Purchased Parts	$6,409

SCHEDULE C

TRAVEL COSTS

A. Item: Trip to Limnology Laboratory- Madison, Wisconsin

1. Plane Fare (round trip)	$300
2. Local Transportation	50
3. Meals (3)	30
4. Lodging (one night)	35
Total for one trip	$415
Two trips required (415x2)	
Total transportation item A	$830

B. Item: Trip to Washington, D.C.

1. Train Fare (round trip)	50
2. Local Transportation	50
3. Lodging (one night)	35
4. Meals (2)	10
Total for one trip	$145
Five trips required (145x5)	
Total transportation item B	$725

C. Total Travel & Lodging Costs:

a. Transportation	1200	
b. Subsistence	355	
Total Travel		$1,555

VII. CONTRACTUAL DATA:

1. Type of Contract

This proposal is submitted on a cost plus fixed fee basis and assumes that any resultant contract will incorporate mutually agreeable Cost Reimbursement terms and conditions.

2. Proposal Validity

This proposal is valid for three months from the date of submittal.

3. Period of Performance

The period of performance is twelve (12) months from the start date.

4. Place of Performance

This program will be conducted at the General Sensors facilities located at 500 Office Center Drive, Suite 130, Ft. Washington, Pa. 19034.

5. Payments

General Sensors, Inc. will bill the Government bimonthly for the costs plus applicable fee. It is requested that the contract schedule denote that all payments made to General Sensors for any contract resulting from this unsolicited proposal be mailed to:

General Sensors, Inc.
500 Office Center Drive, Suite 130
Ft. Washington, Pa. 19034

6. Contract Negotiations

For the contract negotiations and the officer authorized to bind the offeror will be:

Mr. Harry Sadjian, President
500 Office Center Drive, Suite 130
Ft. Washington, Pa. 19034
Telephone: (215) 646-7688

7. Deliverable Items

The deliverable items under this proposal will be six(6) letter-type reports and one final report two(2) months after the end of the study. A fabricated simulator will be delivered to the Government at the location specified by the Scientific Officer of this program.